



UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

ALTERATION OF MUSCOVITE AND BIOTITE IN THE SOIL

By I. A. DENISON, *Assistant Chemist*, WILLIAM H. FRY, *Associate Soil Petrographer*, and P. L. GILE, *Senior Chemist, Division of Soil Chemistry and Physics, Soil Investigations, Bureau of Chemistry and Soils*

CONTENTS

	Page		Page
Introduction.....	1	Alteration in particles differing in clearness of the interference figure.....	15
Review of literature.....	2	Nature of the alteration.....	18
Plan and methods.....	3	Mica in different horizons of the soil profiles.....	24
Description of soils.....	5	Summary.....	30
The chemical composition of the mica samples.....	8	Literature cited.....	32
Differences in composition of mica particles as related to size.....	13		

INTRODUCTION

A comprehensive knowledge of the development of a soil is dependent on an understanding of the changes which the soil minerals undergo from the time they are exposed to weathering as part of the parent rock until they are completely transformed into colloidal material. Thus far in the quantitative study of the soil profile attention has been directed chiefly to the accumulation of clay or colloidal material at different depths and to changes in the gross chemical composition of the soil material in the various horizons. Changes in the individual mineral constituents have received little attention, especially those changes which take place in the deeper parts of the profile below the layer of clay accumulation.

It is recognized that certain minerals, such as hornblende, may disappear relatively soon in the soil-forming process and that others, such as quartz, persist in the upper soil horizons. Up to the present, however, the comparative rates of disappearance of the minerals have not been studied in a quantitative manner. Very little is known in regard to the formation of secondary minerals from decomposition of the original minerals of the soil, except what may be inferred from geologic studies and from studies restricted to the colloidal part of the soil. Finally, the changes in composition which minerals may undergo in the soil before they lose their identity have received little attention.

This investigation is concerned only with the various changes that take place in the mica group of soil minerals during soil development. It deals with the changes in chemical composition that muscovite and biotite undergo before losing their characteristic appearance and optical properties, with the nature of their alteration products, and with the rates at which they disappear in different soil profiles.

REVIEW OF LITERATURE

Views regarding weathering of the micas seem to be founded chiefly on examinations of decomposing rocks, on studies of the alteration of mica in deposits or in special formations, such as china clay, and on the decomposition of mica under laboratory conditions. Comparatively few investigations deal directly with the weathering of mica in soil. Although it is not to be expected, of course, that the weathering of mica in the soil is necessarily comparable in nature or extent to that obtaining under other conditions, one may reasonably infer that the alterations which take place in mica under either natural or artificial conditions are indicative of what may be expected to take place in the soil.

The general opinion as to the alterability of white mica or muscovite is expressed by Clarke (3)¹:

Muscovite, under ordinary conditions, is one of the least alterable of minerals. The feldspar of a granite may be completely kaolinized, while the embedded plates of mica retain their brilliancy almost unchanged.

Concerning the nature of the alteration, Van Hise (16) makes the following statement:

One of the most frequent alterations [of muscovite] is that of hydration, a part of the potassium being replaced by hydrogen; or at the same time it may take up other bases and thus the mineral may pass into vermiculite, a somewhat indefinite compound to which no formula can be assigned.

Blanck (1), after reviewing the opinions of others and in the light of his own investigations on muscovite as a source of potash for plants, comes to the following conclusions:

(1) Muscovite as well as biotite releases potash to plants, and both are as well adapted for supplying potash as potash feldspar. (2) The release of potash to plants by muscovite is in opposition to the prevailing opinion as to the capacity of this mineral to weather, pointing, as it does, to an actual weathering. This appears to consist in removal of potash but with preservation of the external physical properties of the mineral.

Finally Lacroix (12) in studies on the laterites of Guinea finds that the weathering of muscovite under lateritic conditions results in loss of alkalies, particularly of potash, with a corresponding gain in water, the end product of weathering having essentially the composition of kaolinite.

Hickling (10), Galpin (7), and Selle (15) conclude from petrographic studies on china clays that considerable of the kaolinite present is derived from the alteration of secondary muscovite, which they consider to have been derived from the feldspars. China clays, however, differ widely from soils in their nature and perhaps in their origin. Consequently, such transformations can not be assumed to hold for soils except in so far as they are borne out by a special investigation of mineral alteration under soil conditions.

Although considerable difference of opinion exists as to the alterability of muscovite, there is general agreement that biotite is readily altered. To quote Clarke (3):

Unlike muscovite, biotite and phlogopite alter easily, and pass into a series of apparently indefinite substances known as "vermiculites." The change, however, is very simple, and consists merely in the replacement of the alkaline metals by hydrogen, with assumption of additional, loosely combined water. From the typical ferromagnesian micas the following derivatives are thus formed:



¹Italic figures in parentheses refer to Literature cited, p. 32.

Zschimmer (18), proceeding on the ground that specific gravity is an index of degree of weathering, divided a mass of biotite into different fractions according to specific gravity and determined the chemical composition of the fractions. His conclusions may be summarized in the statement that alteration of biotite consists in an exchange of constituents whereby K_2O , Fe_2O_3 , and FeO diminish in favor of H_2O , Al_2O_3 , and MgO . The weathering products of biotite are not, according to Zschimmer, identical with those derived from the weathering of muscovite.

Glinka (9), studying the biotite of southwest Russia, concluded that the end product of the weathering of this mica under certain conditions was a substance resembling kaolinite in composition. The alteration process consisted in a loss of Fe_2O_3 , FeO , MgO , K_2O , and Na_2O but a gain in H_2O . Coincident with these chemical changes there was a diminution in specific gravity and a marked change in color from black to dark gold, to silver, and finally to white.

From a review of the literature on alteration of mica, one may conclude that muscovite, although not unalterable, is much more resistant to change than biotite. The chemical nature of the alteration process of both micas is held to be essentially a replacement of potash by hydrogen. In the case of biotite, not only may potash be lost but also magnesia and iron, although there is some difference of opinion between Glinka and Zschimmer as to the loss of magnesia. The former attributes Zschimmer's failure to observe loss of magnesia to the fact that he investigated only the early stages of weathering.

With regard to the extent to which muscovite and biotite may alter under general conditions of weathering and still retain the characteristics which identify them as mica, the literature is very indefinite. Biotite, to judge from the work of Glinka, may alter but a slight degree before it passes into a material which is no longer to be considered mica. The muscovite particle, on the other hand, apparently retains its external structure until it is transformed into colloidal material and kaolinite (12).

The problem of the comparative rates at which muscovite and biotite disappear has not been specifically investigated. Nevertheless, the general opinion seems to be that muscovite disappears much less rapidly than biotite, presumably by reason of its greater resistance to chemical change induced by weathering agencies.

Although few of the studies and observations that have been made have dealt directly with soil mica, it is probable that the facts established apply in some degree to the decomposition of mica under soil conditions. However, in view of the variable conditions of decomposition in different soil types and in different horizons of the same type, the facts that have been established may not be applicable to all soils.

PLAN AND METHODS

In order to study the changes in chemical composition that muscovite and biotite undergo in the soil, samples of mica were isolated from many soil horizons. These samples of practically pure mica were analyzed, the proportions of muscovite and biotite determined petrographically, and the compositions of the samples compared with those of fresh muscovite and biotite. The rates at which the two micas

disappear in the development of several soil profiles were studied by estimating the quantities of mica present in various horizons.

The method employed for isolating mica from the soil depends on the slow subsidence in water of mica particles as compared with the subsidence of similar-sized particles of other minerals. A separation of the greater part of the total soil mica from the other soil constituents can thus be made by successive decantations of a soil dispersed in water. The details of the process follow.

A 300 to 600 gram sample of soil was dispersed in 3 liters of water by rubbing the soil lightly between the fingers. The suspension, after a moment's settling in a beaker, was decanted upon a 200-mesh sieve. On the sieve were retained mica, particles of organic matter, small colloidal aggregates, and small mineral particles, while the dispersed colloidal material, together with the finest mineral particles, passed through the sieve and were discarded. The mass of soil in the beaker was dispersed as before and the suspension decanted, the process being repeated until the mica was practically removed from the residue of other minerals.

In order to purify the mica from particles of organic matter and minerals that were decanted with it, the contents of the sieve were transferred to a large beaker, water was added, and the floating particles of organic matter were poured off as soon as the mica had settled. The mica was then removed from the accompanying minerals by successive decantations as before. Mica samples prepared from soils which contained but few fine mineral particles other than mica were sufficiently pure at this point; but when the fine particles were very numerous a further treatment was necessary. In this latter case the dried sample was transferred to a large porcelain dish, which was rotated in such a way that the sample passed over the entire inner surface of the dish. The mica flakes adhered closely to the dish, from which they were removed with a camel's-hair brush. Successive rotations of the dish were made with removal of the adhering mica, until the residue was practically free of mica. Microscopic examination of all the samples showed that mica isolated by this method was practically free from other minerals.

The samples of mica isolated in this way contained practically all the medium and coarse mica particles that were in the soil but none of the mica of silt size, since all soil material passing through a 200-mesh sieve was discarded in the procedure. However, in most cases the samples comprised the greater part of the total soil mica.

In general the material identified as muscovite showed an optic axial angle, $2V=35^{\circ}$ to 44° : That identified as biotite showed an angle $2V=0^{\circ}$ to 24° . A few particles were encountered that had an angle between 24° and 35° , but the quantity was inappreciable in any one sample. It is recognized that the measurement of the angles of particles having very blurred interference figures is subject to considerable error; but it is believed that errors in measurement were not sufficiently great to confuse the identification of muscovite and biotite because of the wide difference in their axial angles.

The microscopic examination of the quantities of muscovite and biotite present in the samples was made by the usual petrographic procedure, supplemented by the method for areal counts described in a previous publication (6). However, the very large surface area of the mica particle as compared to its volume suggested the possibility

that the method of areal counts might not be accurate when applied to such material. Therefore it seemed advisable to check the method by comparison with synthetic mixtures of known composition. For this purpose muscovite and biotite were ground separately in a ball mill to degrees of fineness corresponding to the sizes of sand and silt particles. The powdered mica was then made up into four samples containing muscovite and biotite in various proportions. Sample No. 2 was composed of material which did not pass a 200-mesh sieve, and the other three samples were composed of material that had passed through the 200-mesh sieve. The results are given in Table 1.

TABLE 1.—*Microscopic estimation of muscovite and biotite in artificial mixtures*

Mixture No.	Muscovite		Biotite	
	Esti- mated	Present	Esti- mated	Present
	<i>Per cent</i>	<i>Per cent</i>	<i>Per cent</i>	<i>Per cent</i>
1.....	47.5	50.0	52.5	50.0
2.....	35.6	33.3	64.4	66.7
3.....	27.2	25.0	72.8	75.0
4.....	70.4	75.0	29.6	25.0

The degree of accuracy attained, it is believed, is sufficient to render the petrographic method applicable to the estimation of mica of sand and silt sizes.

In all the samples of soil mica that were isolated there were present to a greater or less extent particles which had the external appearance and the refractive index of mica within allowable limits of variation. Since, however, the chief group characteristic, i. e., the interference figure, was lacking in these particles, the material could not definitely be identified as mica. In any given sample of soil mica all gradations of distinctness in the interference figures were observed. Since all the interference figures which could be recognized showed axial angles which approximated those of muscovite and biotite, this fact suggests, at least, that the material with indeterminate figures is more closely related optically to the micas than to any other substances. Therefore, in the identification of the minerals in the isolated samples this material was provisionally classed as mica.

The sodium carbonate fusion method, as described by Hillebrand (11), for the analysis of silicate rocks was followed in analyzing the samples. Combined water was estimated by deducting from the loss on ignition the organic matter, which was determined as CO₂ by the dry-combustion method, using the factor 0.471.

DESCRIPTION OF SOILS

The samples of soil chosen for the isolation of mica represent the important residual micaceous soils of the general region of the piedmont plateau. These soils have developed under generally similar climatic conditions, but differences in weathering sufficient to cause the development of series as diverse as the Cecil of the southern piedmont and the Manor and Chester of the northern piedmont are represented. However, wide differences in weathering conditions, such as obtain between arid and humid soils, and many kinds of parent material are not covered by these samples. It is therefore possible that the conclusions from this investigation may not apply to all soils. Data concerning these samples appear in Table 2.

TABLE 2.—Description of soil samples

Profile No.	Soil type	Depth	Horizon	Description	Parent rock	Location
1.....	Porters loam.....	<i>Inches</i> 0 to 4.....	A.....	Brown loam.....	Gneiss.....	Rutherford County, N. C.
		14 to 48.....	B ₁	Reddish-brown friable clay.		
		48 to 60.....	C ₁	Reddish-brown friable clay.		
		60 to 72.....	C ₂	Gray disintegrated gneiss.		
		72 to 96.....	C ₃	Light-gray partly disintegrated rock.		
		96+.....		Bedrock.....		
2.....	Cecl clay loam.....	8 to 24.....	B ₁	Red stiff clay.....	Mica schist.	Chambers County, Ala.
		25 to 59.....	C ₁	Light-red friable clay loam.		
		60 to 168.....	C ₂	Reddish-yellow, friable, micaceous, partly decomposed rock.		
		169 to 240.....	C ₃	Disintegrated rock.....		
3.....	Cecl clay loam.....	6 to 40.....	B.....	Red, stiff, brittle clay.....	Gneiss.....	Rutherford County, N. C.
		40 to 60.....	B ₂	Yellowish-red friable clay.		
		60 to 84.....	C ₁	Reddish-yellow partly decomposed rock.		
		84+.....	C ₂	Gray disintegrated rock.		
4.....	Cecl clay loam.....	0 to 5.....	A.....	Reddish-brown clay loam.	do.....	Do.
		5 to 36.....	B ₁	Red, stiff, brittle clay.		
		72 to 96.....	C ₁	Brownish-red, friable, partly decomposed rock.		
		96 to 112.....	C ₂	Gray, soft, disintegrated rock.		
		112+.....	C ₃	Soft rock.....		
5.....	Ashe loam.....	0 to 6.....	A.....	Grayish-brown loam.....	Gneiss.....	Buncombe County, N. C.
		6 to 30.....	B.....	Yellow friable clay.....		
		36+.....	B.....	Bedrock.....		
6.....	Louisa sandy clay loam.	30 to 40.....	B.....	Red micaceous clay loam.	do.....	Spartanburg County, S. C.
7.....	Cecl fine sandy loam.	61 to 82.....	B ₂	Red friable clay loam...	Mica schist.	Do.
		138 to 158.....	C ₂	Yellowish-brown partly decomposed rock.		
8.....	Cecl sandy clay loam.	$\frac{1}{2}$ to 4.....	A.....	Reddish-brown loamy fine sand.	do.....	De Kalb County, Ga.
		17 to 22.....	B.....	Red friable fine sandy clay.		
		86 to 108.....	C ₁	Yellowish-red partly decomposed rock.		
		180 to 198.....	C ₂	Grayish-brown disintegrated rock.		
9.....	Madison sandy loam.	7 to 18.....	B ₁	Red, stiff, brittle clay.....	Quartz in mica schist.	Lamar County, Ga.
	Madison gravelly sandy loam.	18 to 30.....	B ₂	Light-red friable, micaceous clay.		
	Madison gravelly loam.	30+.....	C.....	Purplish partly decomposed rock.		
10.....	Georgeville silty clay loam.	6 to 34.....	B ₁	Deep-red silty clay.....	Carolina slate.	Northampton County, N. C.
		34 to 48.....	B ₂	Light-red friable silty clay.		
		48 to 60.....	C.....	Purplish partly decomposed rock.		
11.....	Manor loam.....	$\frac{1}{2}$ to 8.....	A.....	Light-brown mellow loam.	Mica schist.	Harford County, Md.
		18 to 28.....	B.....	Brownish-yellow friable clay loam.		
		32 to 50.....	C.....	Light-brown partly decomposed rock.		

TABLE 2.—Description of soil samples—Continued

Profile No.	Soil type	Depth	Horizon	Description	Parent rock	Location
12....	Manor loam.....	<i>Inches</i> 8 to 15....	B....	Yellowish-brown clay loam.	Mica schist.	District of Columbia.
		60 to 72....	C....	Grayish-yellow partly decomposed rock.		
		72+.....	Bedrock.....		
13....	Manor loam.....	0 to 7.....	A....	Light-brown micaceous loam.	do.....	Montgomery County, Md.
14....	Chester loam.....	12 to 18....	B....	Brown friable clay.....	do.....	Arlington County, Va.
		30 to 36....	C ₁ ...	Yellowish-brown friable micaceous clay loam.		
		45+.....	C ₂ ...	Yellow partly decomposed rock.		
15....	Chester loam.....	18+.....	C....	Yellowish-red friable micaceous loam.	Oneiss.....	Carroll County, Md.
16....	Durham sandy loam.	0 to 7.....	A....	Light-gray loose sandy loam.	Granite gneiss.	De Kalb County, Ga.
		19 to 36....	B....	Light, mottled, yellowish-brown sandy clay loam.		
		51 to 73....	C ₁ ...	Mottled yellowish-red, yellow, and gray partly decomposed rock.		
		91 to 102....	C ₂ ...	Very light-gray slightly decomposed rock.		
		103 to 110....	C ₃ ...	do.....		
		110+.....	Bedrock.....		
17....	Cecil clay loam.....	10 to 42....	B ₁ ...	Red friable clay loam.....	Granite.....	Troup County, Ga.
		43 to 90....	B ₂ ...	do.....		
		91 to 180....	C ₁ ...	Reddish-yellow friable loam.		
		253 to 278....	C ₂ ...	Light-gray, partly decomposed rock.		
18....	Cecil clay loam.....	40 to 65....	C ₁ ...	Pale-reddish clay loam.....	Oneiss.....	Hall County, Ga.
		65 to 100....	C ₂ ...	Pinkish-brown decomposed rock.		
		150+.....	C ₃ ...	Grayish freshly decomposed rock.		
19....	Cecil sandy loam.....	151 to 270....	Light-gray disintegrated rock.	Granite.....	Anderson County, S. C.
20....	Appling sandy loam.	10 to 20....	B ₁ ...	Reddish-yellow, stiff, brittle clay.	Gneiss.....	Lamar County, Ga.
		20 to 40....	B ₂ ...	Mottled reddish-yellow and light-red, stiff, brittle clay.		
		40 to 60....	C ₁ ...	Yellow, friable, partly decomposed rock.		
21....	Talladega loam.....	1 to 5.....	A....	Reddish-brown micaceous loam.	Mica schist.	Polk County, N. C.

With the exception of a few taken especially for this investigation, the samples described in Table 2 were selected from the collection of profile samples of the Division of Soil Survey. Thanks are due W. E. Hearn and M. Baldwin for the special samples. For certain phases of this investigation it was sufficient to examine only one or two horizons of a profile, but for study of the changes in mica that accompany soil development three or more horizons of each profile were examined. The profiles selected for obtaining data regarding the alteration and loss of mica during soil development seemed well adapted for the purpose. So far as could be judged by color, texture, and general field appearance the profiles were normally developed and had not recently been disturbed. It is presumed that they were formed from homogeneous parent rocks, but of course this is by no means certain.

THE CHEMICAL COMPOSITION OF THE MICA SAMPLES

The samples of mica isolated from the soil or parent material contained small quantities of other minerals and colloidal material which could not readily be removed. These impurities and the proportions of muscovite to biotite were estimated petrographically. The samples were analyzed by the fusion method, and the actual composition of the pure mica was then found by correcting the analyses for the constituents of contaminating minerals and colloidal material. The compositions of the minerals employed in this correction were obtained by averaging analyses given by Dana (4). Colloidal material present in the mica samples was assumed to have the same composition as colloidal material from the same or related soils.

The compositions of the pure micas which were obtained in this way are given in Table 3. For convenience of comparison, the average compositions of fresh muscovite and biotite are included in this table. The composition given for muscovite is the average of 75 analyses assembled by Boeke (2), and that given for biotite represents the average of 35 analyses selected by Winchell (17).²

² Doelter (5) has assembled a greater number of analyses of both muscovite and biotite, but some of these are considered by Boeke and by Winchell as of doubtful value. Doelter's analyses, however, average about the same as those selected by Boeke and by Winchell.

TABLE 3.—*Compositions of micas isolated from different soils and the average compositions of fresh biotite and muscovite*¹

[Percentages not given undetermined]

Profile sample No.	Soil series from which mica was isolated	Depth	Horizon	Proportion of muscovite to biotite	SiO ₂	TiO ₂	Fe ₂ O ₃	FeO	Fe ₂ O ₃ + FeO as FeO	Al ₂ O ₃	MnO	CaO	MgO	K ₂ O	Na ₂ O	P ₂ O ₅	H ₂ O above 110°
		Inches			Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
1	Porters	0 to 4	A	6:94	45.05	1.41	12.07	0.62	10.86	23.96	0.15	0.73	3.70	4.48	1.35	0.43	8.24
		14 to 48	B ₁	8:92	37.60	1.77	16.02	0.62	15.04	23.10	0.25	10	6.47	4.76	1.85	0.24	9.50
		48 to 60	C ₁	9:91	44.61	0.94	9.77	0.35	9.14	29.43	---	---	3.35	2.80	1.19	---	10.85
		60 to 72	C ₂	13:87	43.61	0.86	7.45	1.04	7.77	30.06	---	---	1.19	2.18	3.11	---	10.49
		21 to 79	C ₃	21:79	42.26	1.31	5.52	4.46	9.43	28.16	.34	---	1.5	2.92	4.52	.26	9.52
2	Cecil	96+	Rock	2:98	35.11	2.99	4.70	20.41	24.64	15.00	.60	.70	7.08	8.96	2.28	.50	2.00
		8 to 24	B ₁	6:94	38.61	2.12	16.18	---	14.56	23.34	---	---	5.70	4.17	.20	---	9.18
		25 to 59	C ₁	8:92	40.16	1.78	13.53	.55	12.73	25.82	---	---	4.52	3.56	.15	---	9.25
		60 to 168	C ₂	11:89	42.54	1.69	11.58	.64	11.06	26.00	---	---	3.66	3.78	.16	---	9.25
		169 to 240	C ₃	14:86	40.06	1.62	12.38	.64	11.78	26.28	---	---	4.81	4.81	.17	---	8.21
3	Cecil	40 to 60	C ₁	11:89	38.80	1.34	12.37	.36	11.50	28.12	---	---	4.16	3.63	.10	---	10.31
		60 to 84	C ₁	12:88	40.88	.95	11.87	.18	9.96	30.58	---	---	2.24	1.88	.02	---	11.42
		84+	C ₃	2:98	33.58	1.66	10.95	4.80	14.66	27.02	---	---	5.24	4.95	.50	---	9.66
		5 to 36	B ₁	26:74	37.96	1.21	12.51	---	11.26	28.09	---	---	4.68	4.14	.29	---	10.93
		72 to 96	C ₁	53:47	40.67	1.34	11.32	.29	10.48	27.27	.14	---	3.35	3.66	.32	.23	10.33
4	Cecil	96 to 112	C ₃	7:93	32.86	1.85	11.43	1.35	11.64	31.11	.05	.20	4.08	3.60	.58	1.26	13.03
	Ashe	0 to 6	A	8:92	52.31	1.09	7.55	---	6.80	24.57	---	---	1.15	2.00	4.06	.34	5.73
		6 to 30	C	50:50	53.02	.92	5.77	1.34	6.53	23.61	Trace	1.20	2.50	4.57	2.84	.19	4.99
		36+	Rock	16:84	38.68	1.68	2.14	16.10	18.03	19.04	Trace	.80	8.23	7.75	1.85	.33	3.24
		30 to 40	B	0:100	41.70	1.08	12.07	0	10.86	26.01	.13	.22	4.50	3.81	.24	.10	10.18
5	Cecil	61 to 82	B ₁	33:67	41.43	2.05	10.17	.74	9.89	28.09	---	---	3.71	3.21	.18	---	10.65
		138 to 153	C ₁	43:57	42.60	.75	10.47	0	9.42	29.72	.04	.66	2.92	2.09	.39	.04	10.92
	Cecil	86 to 108	C ₁	41:59	44.60	1.03	9.50	.29	8.89	26.91	.17	.21	3.74	2.87	.58	.10	9.40
		180 to 198	C ₂	58:42	46.10	1.27	2.44	.28	2.48	34.42	---	---	.96	8.72	.83	---	4.96
		7 to 18	B ₁	100:0	47.02	1.16	1.50	.29	1.65	34.42	---	---	1.01	9.30	.86	---	4.58
6	Madison	20 to 30	C ₂	100:0	45.08	1.08	3.03	.28	3.01	35.25	---	---	.72	6.85	.72	---	7.04
		30+	C	100:0	45.08	1.08	3.03	.28	3.01	35.25	---	---	.72	6.85	.72	---	7.04
		30 to 40	B	0:100	41.70	1.08	12.07	0	10.86	26.01	.13	.22	4.50	3.81	.24	.10	10.18
		61 to 82	B ₁	33:67	41.43	2.05	10.17	.74	9.89	28.09	---	---	3.71	3.21	.18	---	10.65
		138 to 153	C ₁	43:57	42.60	.75	10.47	0	9.42	29.72	.04	.66	2.92	2.09	.39	.04	10.92
7	Cecil	86 to 108	C ₁	41:59	44.60	1.03	9.50	.29	8.89	26.91	.17	.21	3.74	2.87	.58	.10	9.40
	Cecil	180 to 198	C ₂	58:42	46.10	1.27	2.44	.28	2.48	34.42	---	---	.96	8.72	.83	---	4.96
		7 to 18	B ₁	100:0	47.02	1.16	1.50	.29	1.65	34.42	---	---	1.01	9.30	.86	---	4.58
		20 to 30	C ₂	100:0	45.08	1.08	3.03	.28	3.01	35.25	---	---	.72	6.85	.72	---	7.04
		30+	C	100:0	45.08	1.08	3.03	.28	3.01	35.25	---	---	.72	6.85	.72	---	7.04

¹ Complete analyses by I. A. Denison; separate determinations of alkalis and water by G. J. Hough.² In samples 1 to 8, inclusive, mica is chiefly biotite.³ In samples 9 to 21, inclusive, mica is chiefly muscovite.

TABLE 3.—*Compositions of micas isolated from different soils and the average compositions of fresh biotite and muscovite—Continued*

Profile sample No.	Soil series from which mica was isolated	Depth	Horizon	Proportion of muscovite to biotite	SiO ₂	TiO ₂	Fe ₂ O ₃	FeO	Fe ₂ O ₃ + FeO as FeO	Al ₂ O ₃	MnO	CaO	MgO	K ₂ O	Na ₂ O	P ₂ O ₅	H ₂ O
					Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
10.	Georgetown	Inches 6 to 34 34 to 48 48 to 60	B ₁ B ₂ C	99:1 100:0 98:2	46.70	0.43	3.43	0.56	3.65	33.55		0.17	0.75	8.22	0.48		5.28
11.	Manor	1/4 to 8 18 to 28 32 to 50	A B C	92:8 91:9 95:5										8.13	.65		5.00
														6.99	1.52		5.47
														6.85	1.40		7.34
														7.23	1.40		5.81
12.	Manor	8 to 15 60 to 72 72+	B C Rock	72:28 69:34 85:15										7.39	.71		5.65
														6.60	.69		5.70
														8.25	.85		4.53
13.	Manor	1 to 7	B	63:37	46.67	.91	7.05		6.35	28.15	.14	.38	2.86	7.64	.53	0.06	5.06
14.	Chester	12 to 18 30 to 36 43+	B C ₁ C ₂	81:19 78:22 72:28										8.42	.72		5.27
														7.78	.60		6.13
														7.74	.60		5.97
15.	Chester	18+	C	91:9	55.27	.86	6.42	.83	6.61	22.80	.04	.19	1.30	6.77	.64	.08	5.10
16.	Durham	19 to 36 51 to 73 103 to 110	B C ₁ C ₂	98:2 99:1 98:2										7.47	1.14		5.87
														7.28	1.13		7.51
														7.32	1.20		7.83
17.	Cecil	43 to 90 91 to 180 252 to 278	B ₂ C ₁ C ₂	95:5 92:8 56:44	42.21	.43	8.67	.09	7.80	34.12		.28	.08	.32	.37		13.60
					46.75	.28	3.20		2.97	37.01		.20	.49	1.07	.27		12.50
														3.00	.21		10.97
18.	Cecil	40 to 65 65 to 100 150+	C ₁ C ₂ C ₃	96:4 88:12 69:31										4.64	.00		10.12
														3.87	.16		9.71
														4.86	.03		9.73
19.	Cecil	151 to 270	C	89:17	46.11	.84	5.50	.29	5.24	32.53		.20	1.04	4.06	.48		8.95
20.	Appling	10 to 20 20 to 40 40 to 60	B ₁ B ₂ C ₁	93:7 88:12 83:17	48.18	.73	5.15		4.64	31.30		.17	.34	3.78	.63		9.09
														2.68	.46		10.25
														3.68	.33		12.03
21.	Taladega	1 to 5	A	58:42	44.40	1.01	7.28	.29	6.84	30.04	.06	.24	1.33	4.71	.58	.12	9.88
	Average composition of fresh biotite				50.23	2.86	6.33	12.65	18.35	16.30	.74	.73	12.41	8.17	1.06		2.81
	Average composition of fresh muscovite				46.22	.76	2.59	1.55	3.70	33.48	.14	.62	1.26	9.22	1.23		4.64

It is apparent that the micas isolated from the soil proper and from the weathered parent material are very different, with respect to certain constituents, from the average fresh muscovite or biotite, and different also from the mica in the bedrocks of profiles Nos. 1, 5, and 12. The potash content of the soil mica is in general much lower than that of either unweathered muscovite or biotite; in fact, in a few samples potash is almost absent. Combined water, on the other hand, is several times greater in the soil micas than in either fresh muscovite or biotite. Magnesia is very low in samples made up almost exclusively of biotite. Iron, it will be seen, is almost completely oxidized in the mica isolated from the upper soil horizons, whereas fresh muscovite and biotite contain iron, predominantly in the ferrous form.³

These differences between the soil micas and the average fresh biotite and muscovite are evidently not due to the fact that the soil micas are made up of variable proportions of biotite and muscovite. Fresh biotite and muscovite contain approximately the same percentage of potash, both are low in combined water, and neither contains ferric iron in large quantities. Furthermore the differences between the soil micas and the average fresh mica seem too large and too consistent to be explained on the ground that the soil micas originated from fresh biotites and muscovites that were very different in composition from the average. The most probable explanation of the differences is that they were produced by weathering. Table 3 thus gives qualitative evidence that the soil micas as a whole have been altered in potash, combined water, magnesia, and in oxidation of iron.

Although the soil-mica samples as a group are obviously altered in the four constituents mentioned, a further consideration of the data is needed to show the extent of alteration in these constituents. Also something more than a mere inspection of the data is needed to show whether differences between the soil and fresh micas in silica, alumina, and total iron are significant of changes in composition. Before positive conclusions are drawn as to the differences that may be attributed to alteration and the differences that should be allowed for chance variations in the two kinds of mica, it is necessary to consider variability in composition of the fresh micas, variability of the soil micas, and the magnitude of the differences between these two groups. These three factors are given due weight in calculations of mean differences, together with the probable errors of the differences.

Accordingly, the mean difference between all soil micas and corresponding mixtures of fresh biotite and muscovite and the probable error of the difference were computed for each of the six major constituents, SiO_2 , total iron as FeO , Al_2O_3 , MgO , K_2O , and H_2O . The results of the calculation indicate only whether alteration occurs in the whole group of soil micas. This group contains muscovite and biotite mixed in all proportions; hence alteration in the group could be produced by alteration of either one or both micas. To ascertain whether alteration should be ascribed to muscovite, calculations were made of the mean differences between fresh muscovite and a group of nine soil micas which were considered pure muscovite.

³ Although FeO was not determined in most of the A-horizon micas, because of the interference of organic matter, the assumption that iron is completely oxidized in these horizons is justified by the very low contents of FeO in the next lower horizons.

The group averaged 95 per cent muscovite, and no sample contained less than 80 per cent of this form of mica. A similar calculation made for 15 samples of nearly pure soil biotite indicates whether biotite is also altered.

A method⁴ of computing probable error which seemed applicable to this type of problem was suggested by F. D. Richey, of the office of cereal crops and diseases, Bureau of Plant Industry. The authors wish to express their appreciation to Mr. Richey for his valuable assistance and cooperation. The results of the calculations are given in Table 4.

TABLE 4.—Average amounts by which soil micas exceed or fall below fresh micas in various constituents and the probable errors of the mean differences

(Results expressed as percentages of sample)

Data obtained from—	SiO ₂	Fe ₂ O ₃ +FeO as Feo	Al ₂ O ₃	MgO	K ₂ O	H ₂ O
	<i>Per cent</i>	<i>Per cent</i>	<i>Per cent</i>	<i>Per cent</i>	<i>Per cent</i>	<i>Per cent</i>
All samples analyzed ¹	+3.3±0.57	-3.5±0.97	+5.0±0.73	-4.8±0.80	-3.7±0.23	+4.6±0.28
Biotite samples ²	+4.8±0.80	-5.8±1.67	+0.1±0.75	-7.5±1.33	-4.4±0.28	+6.7±0.36
Muscovite samples ³	+1.2±1.02	-0.4±0.82	+0.2±1.19	-1.1±0.49	-3.1±0.42	+3.3±0.43

¹ Results for K₂O and H₂O based on 52 analyses and for other constituents on 32 analyses.

² Results for all constituents based on 15 analyses.

³ Results for K₂O and H₂O based on 22 analyses and for other constituents on 9 analyses.

It is apparent that the samples of soil muscovite as a group are much lower in potash and higher in water than average fresh muscovite. With respect to the other constituents, namely silica, total iron, alumina, and magnesia, the groups of fresh muscovite and soil muscovite are practically identical; the differences shown for these constituents are small and in most cases are less than their probable errors. The group of soil-biotite samples, on the other hand, differs from the fresh biotite group in all constituents, the increased percentages of alumina and water and the decreased percentages of magnesia and potash being especially pronounced. The increase in silica and decrease in iron, although less marked, are still significant. The differences shown by "all samples analyzed," which include samples of muscovite, biotite, and of the mixed micas, are, as would be expected, intermediate between the differences shown by the muscovite and biotite samples.

⁴ The following is Mr. Richey's description of the method used in calculating the probable error. "In computing the probable errors for the mean differences between the soil micas and the fresh micas it is necessary to take into consideration the variations in the fresh micas, the variations in the soil micas, and the correlation between the two series.

"The variance (squared standard deviation) for each computed value for fresh mica, σ^2_F , was taken to be the weighted mean of the variances for biotite (σ^2_B) and muscovite (σ^2_M), the weighting being according to the proportions of biotite and muscovite. Thus the variance for the computed value of a sample of fresh mica with 43 per cent of biotite and 57 per cent of muscovite would be:

$$\sigma^2_F = 0.43 \sigma^2_B + 0.57 \sigma^2_M$$

"The mean of the variances so computed (σ^2_F) gives an estimate of the variation that might be expected in a series of actual samples of fresh mica similar in biotite and muscovite content to the series of computed values.

"The successive differences between the individual samples of soil mica and the computed values for samples of fresh mica containing the same proportions of biotite and muscovite were determined. The variance of these differences σ^2_D , measures the variation of the differences between the soil mica, and the straight line trend of the computed values for fresh mica, the effects of correlation thereby being eliminated.

"The sum of these variances, $\sigma^2_F + \sigma^2_D$, affords a reasonable basis for computing a probable error for the differences between the computed composition of fresh micas and the analyses of the soil micas. The probable error for the mean of D such differences is:

$$\pm 0.0745 \sqrt{\frac{\sigma^2_F + \sigma^2_D}{n}}$$

The differences that have been pointed out as significant—in the case of muscovite, an increase in the percentage of water and a decrease in the percentage of potash and in the case of biotite, increased percentages of water, alumina, and silica and decreased percentages of potash, magnesia, and total iron—are certainly not due to chance variation in random sampling. These differences range from $3\frac{1}{2}$ to 20 times their respective probable errors and correspond to odds from 40 to 1 to millions to 1 against the differences being due to chance. Moreover, the individual differences were preponderantly in one direction, which gives even higher certainties of the differences being significant.

Although the results of Table 4 show with certainty the constituents in which there are significant differences, they do not show with the same certainty the exact extent of these differences. In the case of K_2O , for instance, where the average difference between soil muscovite and fresh muscovite is 3.7 ± 0.23 per cent, the chance that there is a significant difference is infinitely great, since the difference is 16 times its probable error. The chances, however, are only even that the true value of the difference lies within the limits of the probable error, namely, between 3.47 and 3.93 per cent. But it is practically certain that the true average difference lies between the limits set by three times the probable error; namely, between 3.01 and 4.39 per cent.⁵

Inasmuch as these differences are obviously not due to variations encountered in random sampling, it would seem that they should be attributed to partial alteration of the soil micas. Further consideration is given to this conclusion in the section on "Alteration of mica particles differing in clearness of interference figure;" but for the present it may be accepted without further proof.

DIFFERENCES IN COMPOSITION OF MICA PARTICLES AS RELATED TO SIZE

The data regarding alteration that have been discussed apply with certainty only to the average particle in the groups of soil mica samples rather than to all the particles. Unless all the particles are uniform in composition they can not all have been altered to the extent indicated by the analyses. It is very important to know in connection with questions arising in further discussion whether all the particles in any one sample are alike in composition. For instance, certain samples of muscovite are so high in potash that it would seem that they have not been altered at all. The question arises whether in the horizons or profiles from which the samples were isolated the conditions are such that muscovite is not altered. If all the particles are of the same composition as the whole sample, this would appear to be the case. If, however, many particles are much lower in potash than others, it would appear that alteration does take place in the horizon or profile, but that it has progressed in the average particle to only a slight extent.

The appearance of individual particles under the microscope indicates that different degrees of alteration may be represented in the same sample, since the interference figures are much sharper in some

⁵ A difference of three times the probable error gives odds of something over 30 to 1, which is usually considered to represent practical certainty.

particles than in others. It was thought that more conclusive evidence regarding uniformity might be obtained by separating some of the mica samples into fractions of different-sized particles. If the particles are not uniform, it would seem that the smaller particles should show greater alteration than the larger ones. Accordingly, several samples of soil muscovite and biotite were separated by sieving into coarse and fine fractions. The coarse fractions contained particles larger than 0.25 millimeter, and the fine fractions contained particles about 0.07 millimeter in diameter, except in the case of the two samples from Cecil profile No. 8. Here, the coarse fractions contained particles above 0.07 millimeter and the fine fractions particles between 0.07 millimeter and about 0.005 millimeter. These fine fractions were not obtained by sieving samples of previously isolated mica; they were the silt fractions of the whole soils. As it happened these fractions were made up chiefly of mica with some quartz. The analysis of the whole sample corrected for the quartz present gave the composition of the mica. Combined water and potash were determined in the fractions. The results are given in Table 5.

TABLE 5.—Potash and combined water in coarse and fine fractions of soil mica

Profile No.	Soil series from which mica was isolated	Depth of horizon	Proportion of muscovite to biotite	K ₂ O ¹		H ₂ O ¹	
				Coarse fraction	Fine fraction	Coarse fraction	Fine fraction
		Inches	Per cent	Per cent	Per cent	Per cent	Per cent
2 ¹	Cecil	60 to 168	11:89	4.2	2.4	8.4	9.7
2	do.	169 to 240	14:86	4.6	2.0	8.2	11.1
3	do.	60 to 84	12:88	3.3	1.1	10.6	12.0
6	Louisa	30 to 40	0:100	4.3	2.0	9.5	11.8
9 ¹	Madison	18 to 30	100:0	9.4	7.0	4.8	5.7
10	Georgeville	48 to 60	98:2	9.5	5.0	5.5	4.4
12	Minor	8 to 15	72:28	7.5	6.1	6.3	4.7
14	Chester	30 to 36	78:22	7.7	6.0	6.7	6.6
14	Cecil	65 to 100	88:12	5.2	2.7	10.5	9.1
8 ¹	do.	86 to 108	60:40	2.1	0.8	10.9	15.1
8	do.	180 to 198	56:44	2.9	1.4	9.4	15.9

¹ Determinations by G. J. Hough and G. Edgington.

² Samples 2, 3, and 6 predominantly biotite.

³ Samples 9, 10, 12, 14, and 18 predominantly muscovite.

⁴ Samples 8 of mixed micas.

It is evident from Table 5 that the fine fractions of biotite contain only about one-half as much potash as the coarse fractions, and appreciably more combined water. The fine fractions of muscovite are significantly lower in potash than the coarse fractions, but the water content is irregular. It thus appears that different mica particles in the same sample vary considerably in the extent to which they are altered, the fine particles being altered more than the larger.

In view of this conclusion, it would seem that the very fine mica which could not readily be isolated from the soil by the procedure followed is lower in potash and is probably altered more in other constituents than the mica which was isolated. It follows, therefore, that the samples of mica are by no means representative of all of the mica in the soils from which they were isolated, although there is little doubt that they do represent all of the mica in the soils composed of particles of upper silt and sand sizes.

It might also be concluded that even those samples of isolated soil mica which have compositions similar to fresh mica are altered to some extent. The alteration may, however, be confined to the finer particles.

ALTERATION IN PARTICLES DIFFERING IN CLEARNESS OF THE INTERFERENCE FIGURE

The mica particles as a group have been seen to differ significantly in composition from fresh mica, the differences having been ascribed to alteration. There is a possibility, however, that these differences might not be due to alteration. Many samples, as was mentioned on page 5, contained particles which were micaceous in appearance but which could not with certainty be identified as mica because of the absence of an interference figure. These particles seemed to be highly altered mica, but since they could not be positively identified as such it is possible that they might have originated not from mica but from other minerals. The question then arises, might not the samples be made up simply of fresh, unaltered mica particles and of indeterminate particles derived from some other mineral? The indeterminate particles might have a composition so different from mica that their presence in the samples would produce the changes in composition that have been attributed to alteration.

It was, of course, necessary to test this hypothesis, although the appearance of the mica particles indicated that it was incorrect. The distinctively mica particles did not all have the appearance of fresh mica, and progressive variations were shown in refractive index, birefringence, and distinctness of the interference figure between fresh mica and the so-called indeterminate material. Such variations in the optical characteristics of particles positively identified as mica were suggestive of chemical alteration. In order, however, to be more certain that chemical alteration had occurred, it was desirable to gain an idea of the compositions of particles which varied in their optical characteristics.

It did not seem possible to make a perfect separation of the different kinds of particles. However, it was possible to prepare fractions in which particles having distinct, blurred, very blurred, or indeterminate interference figures predominated. By comparing the compositions of such fractions some idea was obtained as to the composition of these kinds of particles.

This partial separation was possible because there seemed to be a relation between the rate of settling of mica particles from water and the degree of blurring, the more highly blurred particles requiring a greater time for settling than the more distinct. The separation was made as follows: A 5-gram sample of mica, to which a few cubic centimeters of water had been added, was rubbed for a few minutes with a rubber-tipped pestle. The material was transferred to a glass cylinder, water was added to a height of 15 centimeters, and the suspension was decanted almost immediately. The material left in the cylinder was resuspended and decanted until microscopic observation showed that it was made up largely of distinct particles. The blurred, very blurred, and indeterminate fractions were prepared from the decanted material in a similar manner, except that a longer settling was allowed for each successive fraction, sometimes 30 minutes for the indeterminate fraction.

The percentages of the different kinds of particles in each fraction were estimated petrographically. The criteria used in identifying the different particles were as follows: Particles which were classified as distinct showed a sharply defined interference figure. In the blurred particles the two hyperbolas forming the interference figure were blurred but showed complete separation at all points (except at the foci, in the case of biotite) as the stage was rotated. The very blurred particles showed a vaguely outlined figure. The indeterminate particles either showed no figure whatever or a figure too vague to permit of identification of the material. The quantities of the different particles in a fraction were estimated by measuring areas. About 100 particles were measured in each sample. Since preliminary measurements showed that the various groups of particles averaged about the same in thickness, and since it may be assumed that the particles in each group had about the same specific gravity, it follows that the percentage of the total surface exposed by each type of particle should correspond roughly to percentage by weight.

Four samples of soil mica—two of biotite and two of muscovite—were each separated into four fractions; the percentages of the different kinds of particles in each fraction were estimated; and the samples were analyzed for potash and water. The data are given in Table 6.

TABLE 6.—*Relation between K_2O and H_2O contents of muscovite and biotite samples and blurring of the interference figure*

Description of sample	K_2O ¹	H_2O ¹	Percentage of each type of particle in the sample			
			Distinct	Blurred	Very blurred	Indeterminate
Muscovite isolated from profile No. 20, Appling series, 20 to 40 inches.....	<i>Per cent</i> 2.6	<i>Per cent</i> 9.9	23.2	35.9	29.6	14.3
Fraction of this sample.....	8.5	6.8	52.2	30.9	11.5	5.4
Do.....	7.3	6.8	37.0	40.6	13.3	9.1
Do.....	.7	14.8	0	6.3	44.8	48.9
Do.....	.6	13.3	0	14.7	35.8	49.9
Muscovite isolated from profile No. 11, Manor series, 32 to 50 inches.....	6.7	6.3	77.9	10.2	3.0	2.0
Fraction of this sample.....	7.7	5.6	93.4	4.3	.6	1.7
Do.....	4.3	9.1	4.9	74.7	12.4	7.9
Do.....	3.3	11.4	0	20.6	63.1	16.0
Do.....	3.8	8.3	0	28.2	26.9	44.9
Biotite isolated from profile No. 6, Louisa series, 30 to 40 inches.....	3.8	10.2	26.2	51.4	13.6	8.7
Fraction of this sample.....	3.8	9.6	37.2	54.1	7.2	1.5
Do.....	3.5	10.8	0	56.7	33.9	9.4
Do.....	2.9	12.2	0	19.3	63.7	17.0
Do.....	3.2	11.2	0	0	19.6	80.4
Biotite isolated from profile No. 2, Cecil series, 60 to 168 inches.....	3.9	8.6	51.7	38.0	7.0	3.3
Fraction of this sample.....	4.6	8.9	68.5	26.5	4.7	.3
Do.....	5.0	8.8	13.5	74.2	8.2	4.1
Do.....	4.1	10.0	4.6	30.9	58.1	6.4
Do.....	2.3	12.3	15.3	7.0	10.2	67.5

¹ Determinations by G. J. Hough.

That chemical alteration is associated with blurring of the interference figure is immediately apparent from the data of Table 6. Those samples and fractions which contain the least potash and the most water are composed predominantly of very blurred and indeterminate particles. Where chemical alteration is less marked most of the particles are distinct or blurred. This relation is especially pronounced in the case of the muscovite fractions. The biotite fractions

show comparatively small differences in potash and water, but the differences correlate fairly well with the degree of blurring. It is of particular significance that marked alteration is evident in many muscovite and biotite fractions in which the quantities of indeterminate particles are so small that they could have only a negligible influence on the composition of the fractions. Consequently the remaining particles—the distinct, blurred, and very blurred particles—which are obviously mica in their optical properties, must, as a group, be considerably altered. These facts dispose of the hypothesis previously mentioned, that the alteration of the mica samples might be only apparent in that the samples might be made up simply of fresh mica particles and of indeterminate particles derived from some other mineral.

A fairly definite idea of the extent to which the distinct, blurred, very blurred, and indeterminate particles have been altered was obtained by calculating from the data of Table 6 the most probable potash content of each kind of particle. In accordance with the method of least squares, a series of 10 observation equations was written for muscovite and a similar series for biotite by equating the sum of the percentages of the different types of particles found in each fraction to the percentage of potash present. The values for potash in distinct, blurred, very blurred, and indeterminate particles which best satisfied each series of equations were then calculated, together with their probable errors, according to methods given by Merriman (14). These data are given in Table 7.

TABLE 7.—Potash content of particles of soil muscovite and biotite, showing interference figures of various degrees of distinctness

Appearance of interference figure	Percentage of potash in—	
	Muscovite	Biotite
	<i>Per cent</i>	<i>Per cent</i>
Distinct.....	8.6±0.9	4.6±0.6
Blurred.....	5.7±1.3	4.5±0.5
Very blurred.....	2.6±2.0	3.2±0.6
Indeterminate.....	-0.5±2.2	2.2±0.5

Although large probable errors are associated with these calculated values for potash, it is apparent that there is a general decrease in potash from the distinct to the indeterminate group. A series of values calculated for combined water would show a similar progression except that the values would follow the reverse order. It may be concluded, therefore, that the mica samples are made up primarily of mica particles which show widely varying degrees of alteration. The fact that a correlation between optical properties and chemical composition extends without obvious break from distinct to indeterminate particles affords some evidence that the so-called "indeterminate" particles may be merely highly altered particles of mica.

It is apparent from the magnitudes of the probable errors given in Table 7 that particles showing the same degree of blurring vary considerably in content of potash, especially the muscovite samples. This observation is also borne out by the data of Table 6. For

example, in those fractions from the Appling soil which contain 0.6 and 0.7 per cent of potash the very blurred particles could not contain over 1.5 per cent K_2O . However, in that fraction from the Manor soil containing 3.3 per cent K_2O , the very blurred particles probably contain about 3 per cent K_2O . Such variability may be due in part to differences in distribution within a group of particles varying somewhat in distinctness of their interference figures, and, consequently, in percentage of potash. It also may be due in part to variations in the compositions of the fresh micas from which the particles were derived.

A feature of the data not so readily explained is the fact that particles of biotite which show a distinct interference figure contain hardly more than one-half the potash normally present in fresh biotite. It is surprising that the appearance of the interference figure of such particles gives no indication of this profound alteration.

The correlation obtaining between potash content and distinctness of the interference figure is of practical importance. In estimating the composition of soils by the petrographic method it is obviously important that the altered compositions of mica particles be taken into account. While the calculated muscovite values are subject to a large probable error, it is preferable to employ these values rather than the average value for potash in fresh muscovite. The biotite values are less variable and can be used with more surety.

It seems obvious from the relations found between distinctness of interference figure and composition and between particle size and composition that all of the isolated mica samples are probably altered to some extent. Data given in Tables 5 and 6 indicate that even samples having a potash content approximately that of fresh mica contain some particles which are smaller than others and some particles which have blurred interference figures. These particles, it has been shown, are lower in potash than the larger distinct particles, which may or may not be altered.

NATURE OF THE ALTERATION

Thus far attention has been devoted chiefly to the extents to which soil micas differ from fresh micas in composition. It has been shown that when muscovite and biotite are altered in the soil there is a decrease in the percentage of potash and an increase in the percentage of water. In the case of biotite there are also increases in silica and alumina, decreases in iron and magnesia, and an oxidation of ferrous iron. The mechanism of these changes and the nature of the material to which the micas are altering have not been considered. Light on these subjects, however, can be obtained from a further consideration of the data.

Presumably none of the isolated samples of soil mica represent a definite end product of alteration, since preceding data show that any sample may contain particles altered to quite different extents. However, an idea of the end products toward which muscovite and biotite are altering can be calculated from the changes that have already taken place, if certain assumptions are made. (1) It is assumed that the end product of alteration would be reached if the changes apparent in the isolated samples were merely carried further. (2) It is assumed that the observed differences in composition between the soil micas and fresh mica represent the exact extent of those changes.

The soil-muscovite samples (those containing over 80 per cent muscovite) differ from average fresh muscovite only in showing a reduced content of potash and an increased content of water. The extent of these differences is given in Table 8 for 10 samples which show evidence of alteration. In calculating these differences the 10 analyses taken from Table 3 were corrected for the small amounts of biotite present.

TABLE 8.—*Deviations of soil muscovite from average fresh muscovite with respect to percentages of potash and water: Decrease in potash compared with increase in water*

Profile No.	Soil series from which the mica was isolated	Depth of horizon	Decrease in K ₂ O	Increase in H ₂ O	H ₂ O K ₂ O
		<i>Inches</i>	<i>Per cent</i>	<i>Per cent</i>	
17.....	Cecil.....	43 to 90	8.9	9.0	1.0
17.....	do.....	91 to 180	8.1	7.9	1.0
20.....	Appling.....	20 to 40	6.5	5.7	0.0
20.....	do.....	40 to 60	5.5	7.4	1.3
20.....	do.....	10 to 20	5.4	4.5	0.8
18.....	Cecil.....	65 to 100	5.3	5.1	1.0
19.....	do.....	151 to 270	5.1	5.3	1.2
18.....	do.....	40 to 65	4.6	5.5	1.2
9.....	Madison.....	50+	2.3	2.4	1.0
11.....	Manor.....	18 to 28	2.3	2.7	1.2
	Average.....				1.0

It is apparent that in nearly every case the decrease in percentage of potash is almost equal to the increase in percentage of water. The most advanced stage of the observed type of alteration would then be reached when the material no longer contained any potash. The water content of the end product is readily calculated. Since average fresh muscovite contains 9.2 per cent K₂O and 4.6 per cent H₂O (Table 3), and since a decrease in percentage of potash is accompanied by an equal increase in water, the water content of the end product would be 13.8 per cent. None of the soil muscovites differ significantly from the fresh material in percentages of silica and alumina (Table 4); it may be assumed, therefore, that further alteration would produce no appreciable changes in these constituents. The calculated composition of completely altered soil muscovite would then be SiO₂, 46.2 per cent; Al₂O₃,⁶ 35.9 per cent; and H₂O, 13.8 per cent. This composition, it will be noted, is essentially that of kaolinite, which is SiO₂, 46.5 per cent; Al₂O₃, 39.5 per cent; and H₂O, 14.0 per cent.

The product toward which the soil biotites are altering may be calculated in a similar manner. The soil-biotite samples, however, differ significantly from fresh biotite in the percentages of six constituents. The extents of these differences are shown in Table 9. The composition of soil biotite given in the table is the average of 15 samples containing 80 per cent or more of biotite, the whole group averaging 91 per cent biotite. The compositions of the samples were corrected for the small quantities of soil muscovite which they contained.

⁶ This value includes 2.4 per cent Fe₂O₃.

TABLE 9.—*Comparison of average compositions of fresh biotite and soil biotite*

	SiO ₂	Al ₂ O ₃	Total iron as FeO	MgO	K ₂ O	H ₂ O
	<i>Per cent</i>	<i>Per cent</i>	<i>Per cent</i>	<i>Per cent</i>	<i>Per cent</i>	<i>Per cent</i>
Average fresh biotite.....	36.2	16.3	18.4	12.4	8.2	2.8
Average soil biotite.....	40.4	26.3	11.9	4.2	3.6	9.8
Difference.....	+4.2	+10.0	-6.5	-8.2	-4.6	+7.0
Difference expressed as percentage of the quantity of the constituent present in average fresh biotite.....	+11.6	+61.3	-35.3	-66.1	-56.1	+250.0

It is seen that alumina, silica, and water have increased in the altered samples to quite different extents. Potash, magnesia, and iron, on the other hand, have diminished more uniformly. The average reduction in these bases is shown in the last line of the table to amount to a little more than one-half of their values in fresh biotite or 52.5 per cent. If, in calculating the composition of the end product of alteration, it is assumed that alteration is complete when all FeO, MgO, and K₂O have disappeared and that they all disappear at the same rate, then the average composition of the soil biotites shown in Table 9 represents 52.5 per cent of complete alteration. The difference of +4.2 per cent SiO₂, +10 per cent Al₂O₃, and +7 per cent H₂O might then be considered as the changes in these constituents accompanying 52.5 per cent of complete alteration. The increased percentages accompanying complete alteration would thus be +8 per cent SiO₂, +19 per cent Al₂O₃, and +13.3 per cent H₂O. These values added to the respective percentages of the constituents in average fresh biotite would give as the composition of the end product: SiO₂, 44.2 per cent; Al₂O₃, 35.3 per cent; and H₂O, 16.1 per cent. This again is about the composition of kaolinite.

The preceding calculations indicate at best only that the samples of muscovite and biotite are tending toward kaolinite in their alteration. One of the basic assumptions, that the extent of alteration in the various constituents is shown by the differences in composition between the fresh and the soil micas, holds only within certain limits. As pointed out on page 12, these differences in composition are subject to more or less probable error; hence the differences that can be attributed with certainty to alteration lie within a certain range of values, the range being two or three times the probable errors. If allowances were made for the probable errors in calculating the composition to which the micas are approaching, a series of values would be obtained for the composition of the end product. This series as a whole would vary rather widely around the calculated composition, which has been given as that of kaolinite. Whether kaolinite is actually formed in the soils is, of course, at this point highly speculative.

Some information regarding the nature of the change that has already taken place in the muscovite samples can be obtained from the data given in Table 8. The equality that obtains between the increased percentages of water and the decreased percentages of potash shows that the alteration is not a simple replacement of potassium by hydrogen in stoichiometric proportions, the molecular weight of potash being approximately five times that of water. It is,

of course, possible to assume that there is a replacement of potassium by hydrogen and that this is accompanied by the addition of several molecules of water of hydration; but a more probable explanation will be developed later.

Similar evidence regarding the nature of the alteration can be obtained for the soil biotites. Table 10 shows that in the case of the biotite samples also, fairly constant relations obtain between the increased percentages of water and the decreased percentages of potash, magnesia, and iron. From the constancy of these relations the question naturally arises whether alteration of biotite is not simply a substitution of water for these three constituents. Apparently this is not the case. When the molecular compositions of average fresh and altered biotite were compared, and it was assumed that either alumina or silica was unchanged, it was found that the gain in water was not equivalent to the total losses of potash, magnesia, and iron, or to any combination of them. Apparently, then, neither in the case of biotite nor in the case of muscovite is the alteration a simple replacement of bases by hydrogen in equivalent quantities.

TABLE 10.—*Deviation of soil biotite from average fresh biotite with respect to percentages of H_2O , K_2O , MgO , and FeO : Increases in H_2O as compared with decreases in other constituents*

Profile No.	Soil series from which biotite was isolated	Depth of horizon	Increase in H_2O	Decrease in K_2O	Decrease in MgO	Decrease in FeO	$\frac{H_2O}{K_2O}$	$\frac{H_2O}{MgO}$	$\frac{H_2O}{FeO}$
		<i>Inches</i>	<i>Per cent</i>	<i>Per cent</i>	<i>Per cent</i>	<i>Per cent</i>			
4.....	Cecil.....	96 to 112...	10.6	4.8	8.1	6.2	2.2	1.3	1.7
4.....	do.....	60 to 84.....	0.1	6.8	10.0	7.6	1.3	.9	1.2
1.....	Porters.....	48 to 60.....	8.4	5.7	10.1	8.9	1.5	.8	1.0
1.....	do.....	60 to 72.....	8.1	5.6	10.0	10.0	1.4	.8	.8
3.....	Cecil.....	40 to 60.....	7.8	5.0	7.8	6.0	1.6	1.0	1.3
6.....	Louisa.....	30 to 40.....	7.4	4.4	7.9	7.5	1.7	.9	1.0
1.....	Porters.....	72 to 96.....	7.2	4.1	9.0	7.2	1.8	.8	1.0
3.....	Cecil.....	84+.....	7.1	3.2	7.1	3.4	2.2	1.0	2.1
1.....	Porters.....	48 to 60.....	6.0	3.5	5.4	2.4	2.0	1.3	2.9
2.....	Cecil.....	60 to 168...	6.7	4.7	8.3	6.4	1.4	.8	1.0
2.....	do.....	25 to 59.....	6.6	4.8	7.6	4.9	1.4	.9	1.3
2.....	do.....	8 to 24.....	6.4	4.2	6.3	3.2	1.5	1.0	2.0
2.....	do.....	169 to 240..	5.4	3.6	6.9	5.4	1.5	.8	1.0
1.....	Porters.....	0 to 4.....	5.4	3.9	8.4	7.1	1.4	.6	.8
5.....	Ashe.....	0 to 6.....	2.7	4.2	10.3	11.3	.7	.3	.2
	Average.....						1.55	.88	1.30

It would seem that any explanation of the changes that the soil micas have already undergone should take into account the relations between water and other constituents that have been pointed out. These relations are so constant for data of this kind that they are probably significant. All these relations, the equality between the increased percentages of H_2O and the decreased percentages of K_2O in the muscovite samples and the constant proportions between increased percentages of H_2O and decreased percentages of K_2O , MgO , and FeO in the biotite samples, can be explained by the hypothesis that the samples are mixtures of unaltered muscovite or biotite and material of kaolinite composition. It is, of course, evident from the examinations made of particles of varying optical characteristics that such mixtures would not be composed of gross particles of unaltered muscovite or biotite and kaolinite, since the samples contained

few if any particles having the compositions of these minerals. The particle itself, however, might be an isomorphous mixture of muscovite or biotite with kaolinite.

That the compositions of the mica samples may be accounted for by this hypothesis may be seen from the following calculations. If fresh muscovite containing 9.2 per cent K_2O and 4.6 per cent H_2O is mixed in any proportion with kaolinite containing no potash and 14 per cent H_2O , and the composition of the mixture is compared with that of fresh muscovite, it will be found that the increased percentage of water and the decreased percentage of potash will be in the ratio of 1 to 1. It will be recalled that an average ratio of 1 to 1 was actually observed in the case of the muscovite samples. (Table 8.) Since fresh muscovite and kaolinite differ but slightly in percentage of silica or of alumina, the percentages of these constituents would remain practically unchanged in any mixture of the two minerals; and, as a matter of fact, none of the soil-muscovite samples differ appreciably from fresh muscovite in SiO_2 and Al_2O_3 . It follows, therefore, from these relations that the composition of any soil muscovite may be explained by assuming that kaolinite is present in the muscovite particles in some proportion.

Similarly, if biotite containing 8.2 per cent K_2O , 12.4 per cent MgO , 18.4 per cent FeO , and 2.8 per cent H_2O is mixed with kaolinite in any proportion and the composition of the mixture is compared with that of fresh biotite it will be seen that the ratios of the increase in percentage of water to the decreases in percentages of the basic constituents will be as follows:

$$\begin{aligned}\frac{H_2O}{K_2O} &= 1.37, \\ \frac{H_2O}{MgO} &= 0.90, \\ \frac{H_2O}{FeO} &= 0.61.\end{aligned}$$

The average observed ratios were (Table 10):

$$\begin{aligned}\frac{H_2O}{K_2O} &= 1.55, \\ \frac{H_2O}{MgO} &= 0.88, \\ \frac{H_2O}{FeO} &= 1.3.\end{aligned}$$

The discrepancy between the calculated and observed ratios in the case of iron would be explained if a part of the ferrous iron released in the alteration of biotite to kaolinite remained in the mica particles as colloiddally dispersed ferric oxide. The silica and alumina content of the biotite samples is also in accord with the hypothesis that the particles are mixtures of biotite and kaolinitelike material. How well the hypothesis explains the analytical data for all constituents in biotite is shown by Table 11. The average composition of the soil biotite samples is shown in this table, together with the composition of the mixture of fresh biotite and kaolinite, which would have the same percentage of water as the average soil biotite.

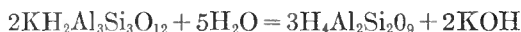
TABLE 11.—Composition of average soil biotite as compared with that of a mixture of fresh biotite and kaolinite

	SiO ₂	Al ₂ O ₃	Total iron as FeO	MgO	K ₂ O	H ₂ O
	<i>Per cent</i>	<i>Per cent</i>	<i>Per cent</i>	<i>Per cent</i>	<i>Per cent</i>	<i>Per cent</i>
Composition of fresh biotite.....	36.2	16.3	18.4	12.4	8.2	2.8
Composition of kaolinite.....	46.5	39.5				14.0
Average composition of soil biotite samples.....	40.4	26.3	11.9	4.2	3.6	9.8
Composition of mixture of fresh biotite and kaolinite having same percentage of water as average soil biotite samples.....	42.6	30.8	6.7	4.7	3.1	9.8

The composition of the mixture of fresh biotite and kaolinite based on percentage of water agrees fairly well with the average composition of the soil-biotite samples in all constituents except FeO. Mixtures having the same content of K₂O, MgO, Al₂O₃, or SiO₂ as the soil biotite would also agree fairly well with the average soil biotite in other constituents. Such variations as occur between the composition of the average soil biotite and the calculated compositions of the mixtures of biotite and kaolinite are no greater than would be expected from the use of an average composition for fresh biotite. Fresh biotite is very variable in composition, particularly in regard to magnesia and iron, and it would be entirely possible for the 15 soil biotites to contain fresh biotite of a somewhat different composition from that used in calculating the composition of the mixture. It is thus apparent that the hypothesis that the samples of altered biotite are composed of fresh biotite and kaolinite in various proportions satisfactorily explains the data.

The optical characteristics of different particles in the mica samples are also in harmony with the hypothesis that the particles are isomorphous mixtures of muscovite or biotite and kaolinite. As previously noted, a general correlation obtains between blurring of interference figure and chemical composition. A close correlation was also observed between blurring of the interference figure and reduction in refractive index and birefringence. Particles having a vague interference figure, or none at all, had a refractive index approaching that of kaolinite and were nearly isotropic. Such optical characteristics would be expected in isomorphous mixtures of mica and kaolinite.

The process by which muscovite and biotite may alter to kaolinite may be regarded as one of hydrolysis. Alteration of muscovite to kaolinite may be represented by the equation:



Biotite may be presumed to alter to kaolinite in accordance with the equation:



It will be noted that alteration of biotite according to this equation would involve the loss of one molecule of silica.

If kaolinite is to be regarded as an alteration product of mica, it might seem that well-defined particles of kaolinite should be present

in the micaceous samples and in soils in general. Such particles, however, were lacking in the mica samples and are of extremely rare occurrence in soils. In some cases the so-called indeterminate material had a composition very close to that of kaolinite. For example, an examination of the mica isolated from profile No. 7, B horizon (Table 3), showed that this sample was made up largely of indeterminate particles. Such particles were of a platy structure, very slightly birefringent, and had a refractive index, 1.56, close to that of kaolinite. They lacked entirely, however, the interference figure characteristic of well-defined kaolinite. If the material were to be classified mineralogically, perhaps it would be as properly called kaolin as kaolinite, although the term "kaolin" is not usually applied to material occurring in such well-defined plates.

MICA IN DIFFERENT HORIZONS OF THE SOIL PROFILES

It has been seen that in all the soils studied biotite contains less potash, magnesia, and iron, and more combined water, silica, and alumina than average fresh biotite. Muscovite in certain soils has a composition differing but slightly from that of normal muscovite, but in other soils it deviates widely from average fresh muscovite in being lower in potash and higher in water. These facts would be stated in terms of the alteration hypothesis as follows: Particles of soil biotite contain considerable material of kaolinite composition; particles of soil muscovite in some soils contain very little kaolinitelike material, but in other soils they may contain a considerable quantity.

For an understanding of soil development it is important to determine when these changes in the composition of mica take place, whether they occur during the initial decomposition of the parent rock or whether they take place after the minerals have become a part of the soil proper. It is also important to compare the various profiles with respect to the degree to which the mica is altered. Differences in alteration may be significant in characterizing different soils or soil series.

The alteration of mica in the development of a soil profile might be expected to be progressive; that is, a slight change in composition in the initial stages of rock weathering with a continuous loss of bases and gain in water as weathering progressed would seem probable. Evidence, however, on this subject can be obtained by comparing the compositions of micas found in the different horizons of the soil profiles. Data for this comparison are given in Table 3.

In considering the alteration of mica in different horizons it is sufficient to observe the potash and water contents of the samples. It has been shown that these constituents exhibit marked changes in percentage when either muscovite or biotite is altered and that the percentages of the other variable constituents parallel the changes in potash and water. The potash contents of mica from profiles Nos. 1 to 8 and 17 to 21, inclusive, are so low that it is evident that alteration has occurred in these profiles, although analyses of the original fresh mica are available in but two instances. Other samples having a potash content near that of fresh mica are probably also somewhat altered, since observation of the individual particles in such samples showed the presence of altered material. (Table 6.)

It can readily be seen that the micas isolated from different horizons above the parent rock are all altered to about the same extent in any one profile. Mica isolated from the lowest part of the C horizon examined shows in each case as marked evidence of alteration as mica occurring in the surface horizon. This is true even when the lowest part of the C horizon consists of soft, only slightly disintegrated rock, as in the case of profiles Nos. 1, 4, 12, and 16. Of course, it can not be stated just where in every profile the most marked change in composition of the mica occurs, but the data of Table 3 indicate that in most profiles this change takes place in the lower part of the C horizon.

It should be pointed out that these data which show an approximately constant composition of mica in different horizons were all obtained on mica samples isolated from the soil material. Since the samples contained only particles above silt size, all finer material having been discarded in the process of isolation, the approximate constancy in composition that has been pointed out properly applies only to those mica particles in the horizons which were between 2 and 0.05 millimeters in diameter. Consideration of other data indicates, however, that a similar constancy in composition probably obtains for the total mica in the horizons. In the lower C horizons of profiles Nos. 2 and 8 to 12, inclusive, so little fine material of any kind is present that practically all the mica in these horizons must have been isolated; hence the compositions of these particular samples shown in Table 3 must represent fairly closely the total mica in these horizons. In other horizons where mineral particles of silt size are relatively abundant the compositions of the total mica would probably be somewhat different from the analyses presented in Table 3, but not markedly so. Analyses given in Table 5 show that the silt-sized mica in horizons C₁ and C₂ of profile No. 8 contain, respectively, 0.8 and 1.4 per cent K₂O, and 15.1 and 15.9 per cent H₂O. The isolated mica samples from these horizons (Table 3) contained, respectively, 2.09 and 2.87 per cent K₂O and 10.92 and 9.40 per cent H₂O. The total mica in these horizons would, therefore, contain potash and water in amounts intermediate between the sets of values given above, the exact values depending on the proportions of silt and sand sized mica in the horizons. It is not unlikely that a similar order of difference obtains between the isolated mica samples and the total mica in the other soils. This difference would tend to make the total mica of the horizon somewhat less constant in composition than appears in the data of Table 3 only in cases in which the horizons showed variations in proportions between silt and larger particles.

The approximate constancy in the composition of mica throughout a profile does not mean that the mica after undergoing alteration in the lower part of the soil profile is thereafter stable and consequently resistant to further change in the upper horizons. It will be shown that large losses of mica occur in the development of many soil profiles; hence the mica in the upper profiles must be undergoing further alteration to clay or kaolin. These facts in terms of the alteration hypothesis previously developed would mean that in the transition of hard to soft rock a certain portion of muscovite or biotite molecules are altered to kaolinite material and that this ratio of muscovite or biotite molecules to kaolinite molecules remains thereafter fairly constant. That this ratio remains fairly constant above the lower C

horizon, although losses in the material as a whole are taking place, would mean that as a given quantity of muscovite or biotite passes into kaolinite above the lower C horizon an approximately equal quantity of kaolinite material passes into the clay or colloidal part of the soil. The two rates of alteration, that of mica to kaolinite and that of kaolinite to clay, must be approximately equal in all horizons of a profile above the lower C, and in all profiles. In the lower C horizons, however, the rate of alteration of mica to kaolinite must exceed that of kaolinite to clay, since if it were here the same, mica in the upper horizons would have the composition of fresh mica according to the hypothesis. It is, of course, possible that in the lowest C horizon, where the composition of the mica seems to be determined, the passage of kaolinite to clay may not take place.

Although the mica within any one profile tends to be fairly constant in composition, there are, in some cases, wide differences between the micas of different profiles. In profiles where muscovite predominates the potash content of the mica varies from 1 to 9 per cent. On the other hand, there are no marked differences in the biotite profiles, the mica in all cases containing about 4 per cent K_2O . Apparently, muscovite may be highly altered in some profiles but only slightly altered in others, while biotite is altered fairly uniformly in all profiles.

The six profiles (Nos. 1 to 6, inclusive, Table 3) in which the mica is chiefly biotite are of the related soil series, the Cecil, Porters, Ashe, and Louisa. Whether biotite present in more diverse series would also be altered to about 4 per cent potash can not, of course, be definitely stated. However, in view of the similarity of the biotite in the A, B, and C horizons, which represent very different degrees of weathering, it would not be expected that biotite in other unrelated soil series would be appreciably different from the biotites that have been studied.

It is somewhat surprising that muscovite should vary so much more widely than biotite in degree of alteration. The marked variability of muscovite is evidently not due solely to the fact that the profiles may have developed under widely different conditions. Muscovites from different profile samples of the same soil series, namely, the Cecil profiles Nos. 17 and 18 from Troup County, Ga., and Lulu, Ga., show greater differences in potash content than the muscovites from such dissimilar series as the Durham, Manor, Chester, Georgeville, and Madison. Since mica is altered to about the same extent in the A, B, and C horizons, it is evident that the explanation for these differences between profiles is to be sought in changes which have occurred not in the developed soil horizons, but in the transition of the parent rock into material composing the lower part of the C horizon.

In accounting for the difference in the extent to which muscovite is altered in the lower C horizons, it might be suggested that the variability in alteration is due to differences in weathering conditions obtaining in the lower C horizons of the several profiles. This explanation, however, does not seem probable, since it is very unlikely that conditions of weathering in the same climatic region vary to any great extent in the zone of decomposing rock. It seems more probable that variability in alteration is to be ascribed to

inherent differences in the nature of the parent rock, or, more particularly, to differences in the nature of the muscovite present.

It is, of course, generally recognized that there are two kinds of muscovite, at least so far as origin is concerned, primary muscovite and secondary muscovite (sericite). Clarke (3), Merrill (13), Van Hise (16), and others consider that secondary muscovite is an alteration product of the potash feldspars; but these writers do not state that this alteration takes place under normal conditions of atmospheric weathering, or whether secondary muscovite differs from primary muscovite in readiness of alteration. However, investigations of china clays by Hickling (10), Selle (15), and Galpin (7) indicate that secondary muscovite may be formed in the atmospheric weathering of granites to clays. Hickling's work goes further in indicating that the secondary muscovite thus formed is much more readily altered than the primary. He points out that in decomposing granite, feldspar is altered only as far as secondary muscovite. In the further decomposition of the rock to china clay, however, the secondary muscovite passes into kaolinite, while much of the primary muscovite persists without obvious alteration.

The presence in the lower C horizons of two kinds of muscovite differing in their rates of alteration would satisfactorily account for the wide differences observed between different profiles with respect to the potash content of the muscovite present. Those profiles in which muscovite has about the same potash content as the fresh mineral would contain on this hypothesis chiefly primary muscovite, since, according to Hickling, this form is slowly altered. Those profiles in which the muscovite is very low in potash would contain chiefly secondary muscovite, which is readily altered. In the other profiles the muscovite would be a mixture of the primary and secondary forms.

Thus far the alteration of mica in different horizons and different soil profiles has been considered only from the point of view of changes in composition of the material. Losses of mica, that is, the disappearance of micaceous-appearing particles, are also of interest in connection with soil studies. In throwing light on the development of soil profiles in general, losses of mica between horizons are of particular interest. Differences in the course or magnitude of losses in different profiles should also be considered as a possible characteristic of individual profiles.

Losses of mica attending the development of soil profiles in general are indicated by the percentages of mica in different horizons. It is, of course, impossible to estimate exactly how much of the original mica is lost in the development of the upper horizons from the parent rock, since nothing is known regarding what quantities of other minerals and of colloidal material may also have been lost. But the percentages of mica in the horizons at least indicate greater losses of mica than of other constituents. In subsequent discussion the term "loss" is used with this implication.

The quantities of mica present in the soil horizons were estimated petrographically. Colloidal material was removed as described in a previous publication of this bureau (8), and the mineral portion was divided into coarse and fine fractions to facilitate the estimation. The quantities of muscovite and biotite in the horizons are shown in Table 12 as percentage of the soil material.

TABLE 12.—Percentages of micas present from various horizons of several soil profiles

Profile No.	Soil series	Horizon	Depth	Quantity of combined muscovite and biotite in horizon	Quantity of muscovite in horizon	Quantity of biotite in horizon	Percentage of muscovite in total mica
			<i>Inches</i>	<i>Per cent</i>	<i>Per cent</i>	<i>Per cent</i>	<i>Per cent</i>
1.....	Porters.....	A.....	0 to 4.....	2	2	0	100
		B ₁	14 to 48.....	3	1	2	33
		C ₁	72 to 96.....	8	2	6	25
		Rock.....	96+.....	22	3	19	14
2.....	Cecil.....	B ₁	8 to 24.....	18	2	16	11
		C ₁	25 to 59.....	72	6	66	8
		C ₂	60 to 168.....	59	7	52	12
		C ₃	169 to 240.....	52	8	44	15
3.....	Cecil.....	B.....	6 to 40.....	12	1	11	8
		C ₁	60 to 84.....	30	10	20	33
		C ₂	84+.....	18	2	16	11
4.....	Cecil.....	A.....	0 to 5.....	4	2	2	50
		B ₁	5 to 36.....	8	2	6	25
		C ₁	72 to 96.....	32	13	19	41
		C ₂	96 to 112.....	25	1	24	4
		C ₃	112+.....	8	0	8	0
5.....	Ashe.....	A.....	0 to 6.....	9	1	8	11
		B.....	6 to 30.....	9	5	4	56
		Rock.....	36+.....	28	3	25	11
8.....	Cecil.....	A.....	½ to 4.....	3	2	1	67
		B.....	17 to 22.....	6	4	2	67
		C ₁	86 to 108.....	72	44	28	61
		C ₂	180 to 198.....	84	49	35	58
12.....	Manor.....	B.....	8 to 15.....	15	11	4	73
		C.....	60 to 72.....	23	15	8	65
		Rock.....	72+.....	13	11	2	85
14.....	Chester.....	B.....	12 to 18.....	20	15	5	75
		C ₁	30 to 36.....	25	28	7	80
		C ₂	45+.....	28	20	8	71
16.....	Durham.....	A.....	0 to 7.....	2	1	1	50
		C ₁	51 to 73.....	9	8	1	89
		C ₂	91 to 102.....	6	6	0	100
		Rock.....	110+.....	5	3	2	60
17.....	Cecil.....	B.....	10 to 42.....	4	2	1	67
		C ₁	91 to 190.....	20	19	1	95
		C ₂	253 to 278.....	21	14	7	67
20.....	Appling.....	B ₁	10 to 20.....	9	7	2	78
		B ₂	20 to 40.....	19	15	4	79
		C ₁	40 to 60.....	17	14	3	82

The percentages of total mica indicate considerable losses of mica between the lowest and the uppermost horizons in most profiles. The loss of mica is especially marked between the upper C and the B horizons, the transition from the B to the A horizon being accompanied by little further diminution in the percentage of total mica. In most profiles there is a progressive decrease in the percentage of total mica from the lowest to the surface horizon; but in several profiles, notably Nos. 3, 4, and 12, the percentage of mica increases markedly in progressing from the lower to the upper C horizon and decreases again in the B horizon.

An obvious explanation for this increase of mica in the upper C horizon is that the part of the parent rock from which this horizon developed may originally have contained more mica than the main mass of the rock which gave rise to the other horizons. A second explanation for the apparent increase of total mica is that in this particular horizon other minerals may have been lost so much more rapidly than mica that the percentage of mica is thereby increased. However, calculation of the minimum losses of other minerals which would be necessary to produce this increased percentage of mica showed

that in several cases unreasonably large losses would be required. For instance, in order that the percentage of total mica in profile No. 4 be increased from 8 per cent of the C_3 horizon to 32 per cent of the C_1 horizon, 94 per cent of other silicate minerals and 79 per cent of quartz would have to be lost. Similar losses would be required to explain the data of profile No. 3. Such losses are, of course, unreasonable, and the explanation on the basis of heterogeneity seems more probable.

It seems peculiar that increases in the quantity of mica should occur so frequently in one part of the profile, the upper C horizon. If the increases are due to heterogeneity of the parent rock, it might be expected that they would occur in the B and A horizons as well. However, if the layer of parent rock from which the A and B horizons were formed had been especially rich in mica, it is possible that this heterogeneity might not now be manifest in these horizons because of extensive decomposition of mica. If these irregularities are attributed to variation in the parent rock, they are obviously not characteristic of the series profile but are merely incidental to the particular location where the profile was sampled. However, some of the data concerning quantities of mica in the various horizons may be taken as characteristic of series profiles.

As previously pointed out, the greater part of the mica present in the upper C horizon has been lost in the development of the B and A horizons. In profiles Nos. 12 and 14 the loss of mica in the transition from the C to the B horizon is much smaller. The smaller proportion of mica lost in profiles Nos. 12 and 14 may be attributed to comparatively slight weathering of the profile. This is borne out by the low colloidal content of these profiles. A high proportion of mica lost may therefore be considered characteristic of highly weathered soils such as the Cecil.

The proportions of muscovite to biotite in horizons of the different profiles are also of interest, since these data should indicate which of the two micas is more resistant to decomposition under soil conditions. The general view of geologists seems to be that of all minerals muscovite is one of the most resistant to weathering, whereas biotite is one of the least resistant. Usually no distinction is made between the resistance of primary and secondary muscovite, although some geologists, Hickling, for example, hold that secondary muscovite is more readily decomposed than the primary form. These views, however, were not based on quantitative estimations of mica in soil profiles.

The comparative rates at which muscovite and biotite have disappeared in the different soil profiles are indicated by the data given in the last column of Table 12. If the proportions of muscovite to biotite (shown by "percentage of muscovite in total mica") in the lower horizons are compared with the proportions in the A or B horizons, it will be seen that they are practically the same in all profiles, except in Nos. 1 and 4. In these two profiles the quantities of both muscovite and biotite in the A horizon are too small to be significant. It would seem, therefore, that muscovite and biotite disappear at about the same rate in soils.

This conclusion is based on a comparison of the upper and lower horizons only. In six profiles—Nos. 2, 8, 12, 14, 16, and 20—the proportion of muscovite to biotite remains fairly constant throughout the profile, which suggests that the two micas disappear at about the

same rate in all horizons of a soil profile. There are four profiles, however—Nos. 1, 3, 4, and 17—in which marked increases in the proportion of muscovite to biotite occurs in the upper C horizon, while the proportion in the A and B horizons tends to revert to that in the lower C horizon.

This variation in proportion of the two micas that has been noted can be explained on the ground of heterogeneity of the parent rock. If this be the true explanation, it is somewhat peculiar that the proportion of muscovite should increase always in the same position in the profile.

A second possible explanation is that secondary muscovite may have been formed in the upper C horizon from alteration of the potash feldspars. The fact that petrographic examination of profiles Nos. 3, 4, and 17 indicates large losses of feldspars between the lower and upper C horizons is in harmony with this idea. If, as has been concluded by others, secondary muscovite may be formed in the decomposition of granitic rocks, it is not unreasonable to assume that it may be formed to some extent as the soil profile subsequently develops. The present data, however, are merely suggestive of this possibility.

In the data given in Table 12 the primary and secondary forms of muscovite are not distinguished. In fact, it is not certain whether both forms or only one form is present; although as has previously been pointed out, there are some grounds for assuming that muscovite in profiles Nos. 12, 14, and 16 may be chiefly primary and that in the other profiles it may be at least partly secondary. The data indicate, however, that whatever form of muscovite is present in the profiles disappears about as rapidly as biotite. On the whole, the loss of muscovite and biotite between horizons seems to depend more on the quantity than on the kind of mica present. It may well be that in those profiles in which appreciable quantities of muscovite have been lost this loss has been confined to the secondary form. In profiles Nos. 12, 14, and 16, where the potash content indicates the presence of primary muscovite (Table 3), a comparison of the upper and lower horizons shows little loss of muscovite. However, neither is biotite lost in these profiles. It thus seems from these data that at least one form and possibly both forms of muscovite are about as readily decomposed in the soil as biotite. Furthermore, in so far as change in composition is concerned, it has previously been pointed out that at least one form of muscovite is, under soil conditions, just as highly altered as biotite.

SUMMARY

This investigation is concerned with changes that take place in muscovite and biotite during soil development. It deals with changes in chemical composition of the two micas, their alteration products, and the quantities lost in the development of different soil profiles. Inasmuch as the micaceous soils examined were all from the region of the piedmont plateau, the results may not hold for all regions.

A satisfactory method for isolating mica particles from soil material in quite pure condition is described. The data obtained comprise complete and partial analyses of 55 samples of mica isolated from one or more horizons of 21 soil profiles, petrographic estimations of the proportions of muscovite and biotite in the mica samples, petrographic estimations of the total quantities of mica present in the material of 39 horizons from 11 selected profiles, and determina-

tions of the potash and water content of soil mica particles differing in size and in optical properties.

A comparison of the chemical compositions of the isolated soil micas with those of average fresh muscovite and biotite shows that the average soil muscovite differs from fresh muscovite in being much lower in potash and higher in water, and that the average soil biotite differs from fresh biotite in containing higher percentages of alumina, silica, and water, lower percentages of magnesia, potash, and iron, and in almost complete oxidation of iron. These differences are so much greater than their probable errors that they are certainly not due to chance variation in random sampling; hence they are attributed to alteration.

All the mica particles in a given soil are not altered to the same extent; the alteration is greater the smaller the particle and the less distinct the interference figure.

Apparently neither in the case of muscovite nor of biotite is the alteration a simple replacement of basic elements by hydrogen. Evidence is presented to show that muscovite and biotite tend to be altered to a material of the composition of kaolinite, and it is suggested that altered particles of soil mica are isomorphous mixtures of muscovite and biotite with kaolinite. The chemical composition of a particle would thus depend on the proportions of the two constituents present.

The mica of any one profile varies little in composition in horizons above the lowest C horizon. Mica in the hard rock, however, may have a quite different composition from that in the upper C or A horizons.

The fact that the total quantities of mica in the different horizons of a profile remain fairly constant in composition, while large losses of mica may be taking place through alteration to clay material, is explained in terms of the alteration hypothesis proposed. According to this hypothesis, a certain proportion of muscovite or biotite molecules may be changed to kaolinite molecules in the lowest part of the C horizon; this same proportion of the two constituents in the total quantities of mica is then maintained in the upper horizons, owing to a balance between the two changes, mica to kaolinite and kaolinite to clay.

In all soil profiles biotite seems to be altered to about the same extent, the potash content of the material usually approximating 4 per cent. Muscovite, on the other hand, in some profiles, may contain less than 1 per cent K_2O and in other profiles as high as 9 per cent K_2O . This variability is attributed to the possibility of two forms of muscovite being present, primary and secondary, the secondary form being more readily altered.

Considerable losses of mica occur in the development of most soil profiles, the loss being especially marked between the upper C and the lower B horizons. In some profiles, however, little loss of mica is indicated. Differences in the loss of mica are attributed to differences in the weathering of the profiles.

Muscovite and biotite do not differ appreciably in the rates at which they are decomposed in the soil, so far as can be judged from the comparative quantities of muscovite and biotite present in various horizons of 11 soil profiles. It is possible, however, that a considerable part of the muscovite lost is the secondary form.

LITERATURE CITED

- (1) BLANCK, E.
1912. DIE GLIMMER ALS KALIQUELLE FÜR DIE PFLANZEN UND IHRE VER-
WITTERUNG. Jour. Landw. 60 : [97]-110.
- (2) BOEKE, H. E.
1916. DIE GRENZEN DER MISCHKRYSTALLBILDUNG IN MUSCOVIT UND
BIOTIT. Neues Jahrb. Min., Geol. u. Paläontol. 1 : 83-125, illus.
- (3) CLARKE, F. W.
1924. THE DATA OF GEOCHEMISTRY. Ed. 5. U. S. Geol. Survey Bul.
770, 841 p.
- (4) DANA, E. S.
1914. THE SYSTEM OF MINERALOGY OF JAMES DWIGHT DANA, 1837-1868.
DESCRIPTIVE MINERALOGY. Ed. 6, entirely rewritten and much
enl. 1134 p., illus. New York and London. (With Appen-
dices I and II, completing the work to 1909.)
- (5) DOELTER, C. G.
1917. HANDBUCH DER MINERALCHEMIE. UNTER MITWIRKUNG VON
ZAHLBREICHEN FACGENOSSEN HERAUSGEGEBEN MIT UNTER-
STÜTZUNG DER K. AKADEMIE DER WISSENSCHAFTEN IN WIEN.
Band II, Abt. 2. SILICATE DREIWERTE METALLE. 1144 p.,
illus. Dresden and Leipzig.
- (6) FRY, W. H.
1923. THE MICROSCOPIC ESTIMATION OF COLLOIDS IN SOIL SEPARATES.
Jour. Agr. Research 24 : 879-883.
- (7) GALPIN, S. L.
1912. STUDIES OF FLINT CLAYS AND THEIR ASSOCIATES. Amer. Ceramic
Soc. Trans. 14 : [301]-346, illus.
- (8) GILE, P. L., MIDDLETON, H. E., ROBINSON, W. O., FRY, W. H., and ANDER-
SON, M. S.
1924. ESTIMATION OF COLLOIDAL MATERIALS IN SOILS BY ADSORPTION.
U. S. Dept. Agr. Bul. 1193, 42 p.
- (9) GLINKA, K. D.
1906. UNTERSUCHUNGEN IM GEBIET DER VERWITTERUNGSPROZESSE.
Soc. Nat. St. Petersburg Trav., Sect. Geol. et Min. 34 (Livr. 5):
1-175, illus.
- (10) HICKLING, G.
1909. CHINA-CLAY: ITS NATURE AND ORIGIN. Inst. Mining Engin. Trans.
(1908-09) 36 : 10-35, illus.
- (11) HILLEBRAND, W. F.
1919. THE ANALYSIS OF SILICATE AND CARBONATE ROCKS. U. S. Geol.
Survey Bul. 700, 285 p., illus.
- (12) LACROIX, A.
1913. LES LATÉRITES DE LA GUINÉE ET LES PRODUITS D'ALTÉRATION QUI
LEURS SONT ASSOCIÉS. Nouvelles Arch., Mus. d'Hist. Nat.
[Paris] (5) 5 : [255]-356, illus.
- (13) MERRILL, G. P.
1906. A TREATISE ON ROCKS, ROCK-WEATHERING AND SOILS. [New ed.]
400 p., illus. New York and London.
- (14) MERRIAM, M.
1892. AN INTRODUCTION TO GEODETIC SURVEYING IN THREE PARTS: I, THE
FIGURE OF THE EARTH. II, THE PRINCIPLES OF LEAST SQUARES.
III, THE FIELD WORK OF TRIANGULATION. 170 p., illus. New
York.
- (15) SELLE, V.
1907. ÜBER VERWITTERUNG UND KAOLINBILDUNG HALLESCHER QUARZ-
PORPHYRE. Ztschr. Naturw. [Hrll] 79 : [321]-421, illus.
- (16) VAN HISE, C. R.
1904. A TREATISE ON METAMORPHISM. U. S. Geol. Survey Monog. 47,
1286 p., illus.
- (17) WINCHELL, A. N.
1925. STUDIES IN THE MICA GROUP. Amer. Jour. Sci. (5) 9 : 309-327,
415-430, illus.
- (18) ZSCHIMMER, E.
1898. DIE VERWITTERUNGSPRODUKTE DES MAGNESIAGLIMMERS UND DER
ZUSAMMENHANG ZWISCHEN CHEMISCHER ZUSAMMENSETZUNG UND
OPTISCHEN ACHSEWINKEL DER GLIMMER. Jenaische Ztschr.
Naturw. (n. F. 25) 32 : [551]-620, illus.

